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THE APPLICATION OF COLOR DISPLAY TECHNIQUES FOR THE ANALYSIS OF NIMBUS INFRARED RADIATION DATA

LEWIS J. ALLISON
G. THOMAS CHERRIX
HAROLD AUSFRESSER

AUGUST 1971

GSFC

GODDARD SPACE FLIGHT CENTER
GREENBELT, MARYLAND

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ABSTRACT

A color enhancement system designed for the Application Technology Satellite (ATS) Spin Scan experiment has been adapted for the analysis of Nimbus infrared radiation measurements.

For a given scene recorded on magnetic tape by the Nimbus scanning radiometers, a virtually unlimited number of color images can be produced at the ATS Operations Control Center from a color selector paper tape input. Linear image interpolation has produced radiation analyses in which each brightness-color interval has a smooth boundary without any mosaic effects. An annotated latitude-longitude gridding program makes it possible to precisely locate geophysical parameters and permit accurate interpretation of pertinent meteorological, geological, hydrological and oceanographic features.

THE APPLICATION OF COLOR DISPLAY TECHNIQUES FOR THE ANALYSIS OF NIMBUS INFRARED RADIATION DATA

INTRODUCTION

The use of color presentation to more readily and accurately perform human discrimination tasks has been the subject of increased interest in the fields of biomedicine, geology, topographic mapping, air pollution and oceanography (Stratton and Sheppard, 1970, Cleveland and McFadden, 1970, Yost et al., 1970, Veress, 1970, Mairs, 1970, and Smith, 1971).

The adaptation of pseudo-color image enhancement techniques to the Advanced Technology Satellite (ATS) data had been pioneered by the ATS Project, at Goddard Space Flight Center (Westinghouse Electric Corporation, 1968, 1970). Subsequent applications were made to Nimbus radiation data by this system (Kreins and Allison, 1970) and by other less sophisticated color depiction systems (Oort, 1970, Szekielda and Mitchell, 1971, Warnecke et al., 1971, Nordberg et al., 1971).

The infrared radiometer flown on the Nimbus 3 meteorological satellite recorded outgoing emitted radiation in the 3.4-4.2 micron "atmospheric window" and detailed observations of the earth's surface and three dimensional cloud structures were made possible from these nighttime measurements. The normal presentation of this data is a black and white photofacsimile image formed scan by scan from the original analog record or as a computer-produced grid print map in a standard geographical map projection (Warnecke et al., 1968, Allison et al., 1971, Shenk and Fujita, 1971). Approximately 6 to 8 grey scale intervals of brightness temperatures could be delineated by eye in the photographic print

while the contoured computer map had its distinctive interpretation problems. The utilization of a computer-produced color grid print map has helped to simplify this radiation data analysis problem because the human eye can distinguish many more colors, i.e., brightness intervals than shades of grey.

This paper will briefly describe the Nimbus 3 radiation experiment and data samples, and the multi-color ATS system used to process the enhanced Nimbus infrared radiation analyses.

The Nimbus 3 High Resolution Infrared Radiometer Experiment

The Nimbus 3 meteorological satellite which was launched 14 April 1969, carried a single channel scanning radiometer, shown in Fig. 1. This high resolution infrared radiometer (HRIR) contained a lead selenide photoconductive cell, which was radiatively cooled and had a peak spectral response in the 3.4 to 4.2 micron "atmospheric window" region (Fig. 2). At night, the radiometer measured radiance temperatures between approximately 210°K and 330°K with a noise equivalent temperature of < 1.5°K for a 280°K background. The radiometer scan mirror rotates the field of view of the detector through 360 degrees in a plane normal to the orbital path and through the earth center. The detector views the housing cavity, outer space, earth, outer space and then the housing cavity. The outer space level serves as a zero reference and together with the radiometer housing, provides for an in-flight check of instrument calibration.

The instantaneous field of view of the instrument is 0.5 degrees and at an average satellite altitude of 1100 km, a 9 km by 9 km scan spot is viewed at the earth's surface at the subsatellite point.

The radiometer produces three identical outputs. Two of these are routed to separate tape-recorder systems (High Data Rate Storage Subsystems — HYDRSS "A" and "B") and the third, Direct Readout Infrared Radiometer (DRIR) is broadcast in real time to ground stations equipped with special Automatic Picture Transmission sets.

The calibration and data reduction methods for daytime and nighttime HRIR data are quite different. The daytime data is reduced to percent reflected solar energy while the nighttime data is reduced to equivalent blackbody temperatures. Since this paper is concerned only with the pseudo-color processing of nighttime HRIR data, the reader interested in daytime HRIR data is referred to the Nimbus 3 Users' Guide (1969) for further details.

At the Data Acquisition Facilities (Fairbanks, Alaska and Rosman, N.C.), the HRIR information is demultiplexed and recorded on magnetic tape. It is transmitted to the Goddard Space Flight Center, where the FM signal is demodulated, synchronized, and displayed on a photofacsimile recorder. The facsimile recorder converts the radiometer analog output signals into a continuous strip picture, line by line, on 70mm black and white film. Blanking circuits in the recorder reject unwanted sections of each scan line. Only the earth scan and small portions of the space scan used for calibration purposes are recorded on this film.

An example of Nimbus 3 HRIR photofacsimile coverage over Hurricane Camille, 1969 on 18 August 1969 as it crossed the Gulf coast at approximate midnight is shown (Fig. 3). This storm, whose maximum surface winds were approximately 175 kts at this time, ranks as one of the most destructive ever to hit the United States, with total damage estimated at 1.42 billion dollars and

258 deaths (DeAngelis and Nelson, 1969). In order for the reader to place this nighttime picture in its proper perspective, Figure 4 is included to show the ground track of Camille with associated daytime coverage by the Nimbus 3 Image Dissector Camera System. This convenient photographic display of the analog data contains an approximate geographic grid superimposed, which has an accuracy of 1° of great circle arc at the sub-satellite point. Severe distortions occur at the sides near the horizons because of the earth's curvature. Only six shades of equivalent blackbody temperatures are distinguishable by the human eye.

The grid print map is a computer transformation of the radiation data, calibrated in equivalent blackbody temperature, in a Mercator map projection. The advantages of this form of presentation are the display of absolute values, the elimination of distortion and the possibility of compositing consecutive orbits into quasi-synoptic area maps. Figure 5 shows the numerical contouring which facilitates the recognition of large cloud patterns over the storm but one still has difficulty in interpreting the various numerically printed brightness intervals. The hand-drawn map (Figure 6) took approximately two days to complete and experienced analysts still had some difficulty in data interpretation without detailed zip-toning or cross-hatching of the brightness intervals (Pouquet, 1969).

Figure 7 shows a color grid print map of Camille, which uses 17 colors and 3 shades of grey, in 5°K intervals. One can at a glance, determine the warm (purple-red) end of the spectrum. These indicate low clouds, ground and/or sea surface temperatures in the Gulf of Mexico and the Gulf Stream. Middle clouds are shown by tan to yellow and high clouds by green, blue and greys. A 1:1 million mercator mapping program was used which averages approximately 3-5 scan

spots at each 1/8 degree of latitude and longitude intersection. More details concerning the basic color principles of display enhancement used in this technique are described by Kreins and Allison (1970).

The ATS Ground Recording and Color Playback System

The ATS Operations Control Center (ATSOCC) at Goddard Space Flight Center has equipment designed to process and color display data from any source, providing it was in the proper format to be accepted by the data processing system. The basic equipment consists of two digital tape decks, a data control unit, and a cathode ray tube film recorder for color and black and white. The data control unit is capable of electronic expansion of selected picture areas and intensity control made possible by a programmable digital look-up table. With normal black and white or color video data input, this intensity control subunit can be set to produce contrast enhancement, contour maps and pseudo-color pictures. These techniques have been proven effective in producing black and white, color and various types of pseudo-color pictures from ATS-1, ATS-3, Nimbus, and Orbiting Astronomical Observatory source data. A generalized overview of the processing capabilities of this facility is shown in Figure 8.

The steps by which the Nimbus infrared data is converted into a color contoured chart is as follows:

The Nimbus analog data is initially received at Fairbanks, Alaska or Rosman, North Carolina Data Acquisition Facility and transmitted to Goddard Space Flight Center, where it is processed by the CDC 930 computer. This Digitized Infrared Radiation Tape with concurrent orbital and altitude information, necessary calibrations and corrections is then processed through an IBM 360 computer

to form the Nimbus Meteorological Radiation Tape (NMRT). The NMRT, an 800 bpi, 7 track tape is used to generate a Map tape and a Picture tape through further processing on the IBM 360.

Mapping programs exist that print the radiation data in standard map projections. The advantages of this form of data display are the presentation of absolute values, the elimination of distortion, and the possibility of automatically compositing measurements of consecutive orbits into quasi-synoptic area charts. The card deck is processed through the SDS-930 computer to produce a Paper tape containing the desired color-brightness temperature scale. This tape is used by the Data Control Unit for the Color Contrast Control Memory. This step is not performed for each pseudo-color map since a given color scale can be rearranged by the IBM 360 before generation of the Picture tape. A new Paper tape is regenerated only if a new color is desired by the analyst.

The Picture tape contains 2400 lines with 8192 words (bytes) per line which is the full resolution of the system. The color map shown in Figure 7 was produced in a 2 times expansion mode using only 1200 lines with 4096 bytes per line. Each word (byte) has a value between 0 and 255. These values can be placed on the tape and manipulated by the IBM 360 so that any color can be easily associated with any selected brightness temperature interval.

Digital tapes recorded at any computer facility in the correct format can be mounted on the data control unit. This unit accepts one line of digital data at a time from the picture tape and after processing, presents this data to the color film recorder.

The processing provided by the data control unit is divided into four major modes (see Figure 9). The first mode, NORMAL, involves no transformation of

the input data; thus a picture unaltered in any way is formed from the input data. The EXPANSION mode effectively increases the film recorder resolution by the expansion factor selected. This expansion of 1, 2, 4 or 8 times (linear, not area) is accomplished by repetition of data samples both horizontally and vertically. This mode is operational in conjunction with any of the following modes. The third mode, CONTRAST, is used to change the normal relationship between the digital sample value and the film density. The technique employs a look-up table implemented using a core memory. This core memory contains an array of 256 eight bit numbers. In operation each eight bit input sample value (0 to 255) is used to address this array; the contents of the addressed location is used as the digital output number. Thus we may transform any input value to an arbitrarily selected output value. The contents of the core memory array may be changed using the Paper tape.

The PSEUDO-COLOR mode is used to transform each input value to a selected color on the color film recorder. Much of the same equipment employed for the CONTRAST mode is used here. A key difference is that three look-up tables are used — one for each output color (green, red, blue).

The data from the data control unit is then processed into the color film recorder which produces a hard-copy film negative using the basic tricolors. A simplified block diagram is shown in Figure 10. The color film recorder is basically a cathode ray tube (CRT) with three color filters inserted between the CRT and the color film. To obtain the three primary colors from a single light source, the CRT source must have sufficient spectral energy distribution to contain frequency components of each primary color. A set of narrow band filters is used; Kodak Wratten filter 47B for blue, 99 for green and 26 for red which closely match the range of the Kodak Ektacolor type S film.

In order to produce a wide range of colors in the Nimbus radiation analyses, the light was varied from 0% to 100% through the three filters and focused with great precision on the color sensitized film.

Table 1 shows a number of examples of the resulting color for various transmissions of blue, green, and red light.

To show the correspondence between input range numbers and the colors, a test pattern was generated. All possible colors were formed for 20% (of maximum intensity) increments of each input. On the basis of these 225 color patches, one can select a set of colors to suit his needs; by interpolation other color patches can be visualized and subsequently produced. The desired relation between the input range numbers on the magnetic tape and the selected colors are expressed in tabular form in Table 2. Thus, for example, all input data whose sample values are between 31 and 60 will be orange in the color image. In general, the color look-up table generated may have as many as 256 rows. The input numbers used in the color chart of Hurricane Camille, 1969 (Fig. 7) is shown in Table 3.

The following describes the more detailed operation of the Electronic Image Systems (EIS) color film recorder in the production of this Hurricane Camille analysis:

The green filter is the first to be placed in front of the lens. The digital video from the Data Control Unit is converted to an analog format, amplified and then applied to the CRT. Using the 2 times expansion mode for each radiation data sample from the digitizer, the CRT spot is deflected horizontally along each line and is imaged on the color film by the lens via the plane mirror. The

green component of each line is thus formed by 4096 intensity modulated spots. Upon the completion of the green line, the filter wheel is advanced so that the red filter is in front of the lens, the horizontal counter is reset and the green video enable is terminated. After waiting 40 milliseconds for the filter wheel to advance, the red digital data is sent to the color film recorder. The video is D/A converted, and a red line of 4096 spots is generated over the green line. After the red data has been exposed on the film, there is another 40-millisecond delay for positioning the blue filter. The blue video line is then displayed. Thus the three colors have been superimposed at the same spot location on the film to form an "integrated" color spot, one of 4096 spots per line. The end of the blue video display increments the vertical counter in preparation for the next tricolor line. The procedure continues to cycle until 1200 tri-color lines have been displayed in approximately 30 minutes. The standard data transfer rate to the color film recorder is 45 kHz. This is the rate for real time buffered operation, digital playback operation (both normal and expanded) and analog playback operation.

CONCLUSION

The color Nimbus radiation analysis which was produced by the ATS Operations Control Center at Goddard Space Flight Center is superior to a black and white picture principally because the human eye can interpret color more readily than the same number of shades of grey. Hence the radiation data originally recorded on the Nimbus satellite is more effectively displayed and interpreted by the human analyst. This color technique has been applied to tornado studies using Nimbus 4 THIR, ITOS-1 and NOAA-1 IR data and will

be used to produce color time-lapse movies over severe weather systems on a 24-hr. basis from the Synchronous Meteorological Satellite IR data during 1972-1973.

ACKNOWLEDGMENTS

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Table 1

Sample Transmission — Color Relationship

Blue T_b (%)	Green T_g (%)	Red T_r (%)	Resulting Color
100	0	0	Blue
0	100	0	Green
0	0	100	Red
0	50	50	Yellow
50	0	50	Magenta
50	50	0	Cyan
$33\frac{1}{3}$	$33\frac{1}{3}$	$33\frac{1}{3}$	White (gray)

Table 2

Color Look-Up Table Example

Input Range	Green	Red	Blue
0 - 10	51	0	0
11 - 30	255	255	0
31 - 60	51	153	0
61 - 100	0	153	0
101 - 255	0	0	51

Table 3

Hurricane Camille, 1969-Color Reference Chart

	Brightness Temperature (°K)	Cloud Height (Km)	Color	Input Level		
				Green	Red	Blue
1.	305 - 300	<0.5	Purple	0	51	255
2.	299 - 295	0.1 - 1.0	Maroon	0	102	102
3.	294 - 290	1.1 - 1.4	Pink	0	255	255
4.	289 - 285	1.5 - 2.6	Red	0	255	0
5.	284 - 280	2.7 - 3.7	Orange	26	255	0
6.	279 - 275	3.8 - 4.7	Beige	51	255	51
7.	274 - 270	4.8 - 5.6	Brown	51	153	0
8.	269 - 265	5.7 - 6.5	Yellow	255	255	0
9.	264 - 260	6.6 - 7.5	Dark Yellow	153	153	0
10.	259 - 255	7.6 - 8.3	Cream	255	255	51
11.	254 - 250	8.4 - 9.0	Pale Green	255	102	51
12.	249 - 245	9.1 - 9.6	Olive Green	102	51	0
13.	244 - 240	9.7 - 10.3	Medium Green	255	0	0
14.	239 - 235	10.4 - 10.9	Dark Green	51	0	0
15.	234 - 230	11.0 - 11.6	Light Blue	153	51	255
16.	229 - 225	11.7 - 12.2	Medium Blue	102	0	153
17.	224 - 220	12.3 - 12.9	Dark Blue	0	0	255
18.	219 - 215	13.0 - 13.4	Grey	32	32	32
19.	214 - 210	13.5 - 14.0	Light Grey	96	96	96
20.	209 - 200	14.1 - 17.0	White	255	255	255

FIGURE CAPTIONS

Figure 1. Nimbus 3 high resolution infrared radiometer (HRIR).

Figure 2. Effective spectral response of the Nimbus 3 high resolution infrared radiometer.

Figure 3. Photofacsimile print of Hurricane Camille, 1969, recorded by Nimbus 3 HRIR at 0530-0538 GMT on 18 August 1969.

Figure 4. Nimbus 3 Image Dissector Camera pictures of Hurricane Camile from its formative stage on 11 August 1969 to its near dissipation on 21 August 1969, with associated ground track.

Figure 5. Computer-contoured grid print map of Nimbus 3 HRIR data over Hurricane Camille, recorded at 0530-0538 GMT on 18 August 1969.

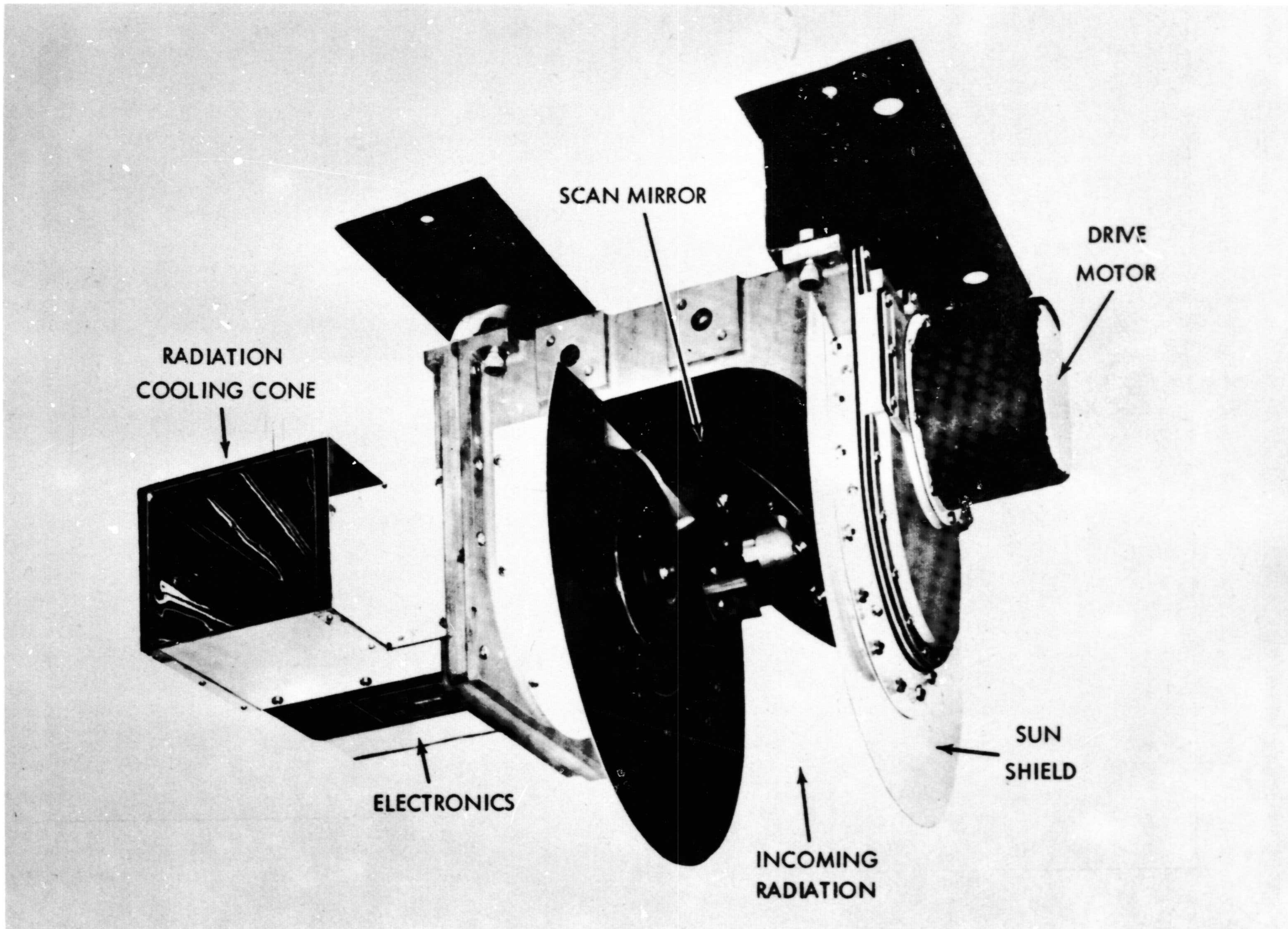
Figure 6. Hand analysis of a computer-produced grid print map of Nimbus 3 HRIR data over Hurricane Camille, recorded at 0530-0538 GMT on 18 August 1969.

Figure 7. Color analysis of Nimbus 3 HRIR data over Hurricane Camille, recorded at 0530-0538 GMT on 18 August 1969 which was produced by the ATS Operations Control Center (ATSOCC).

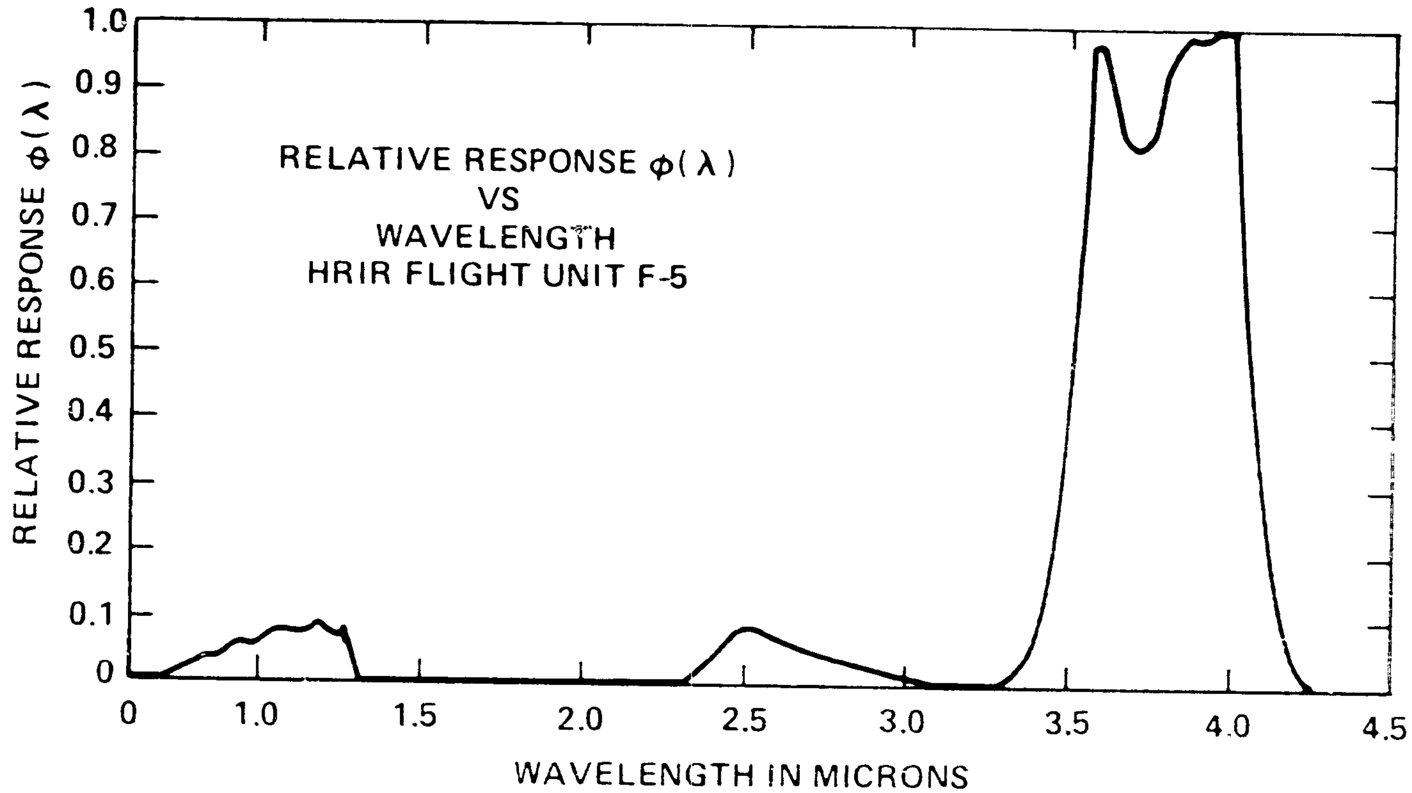
Figure 8. A flow diagram showing the pseudo color processing of Nimbus HRIR data at the ATSOCC.

Figure 9. A flow diagram showing the four modes of operations of the Data Control Unit.

Figure 10. A flow diagram showing the operations of the EIS color film recorder.

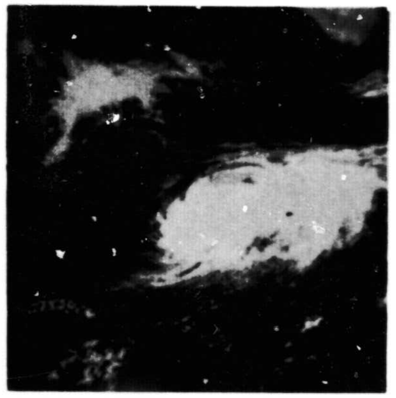


NIMBUS 3 HIGH RESOLUTION INFRARED RADIOMETER



EFFECTIVE HRIR SPECTRAL RESPONSE OF THE RADIOMETER


DATA ORBIT 1688 N
NIMBUS III



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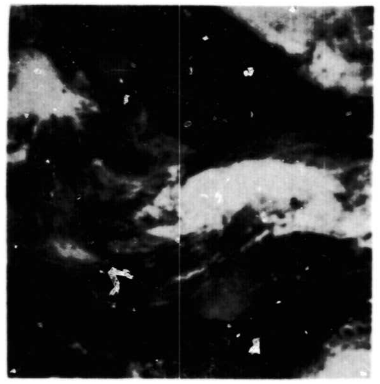

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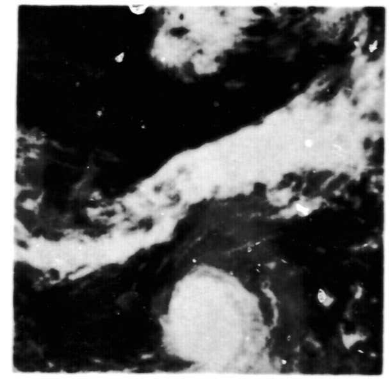

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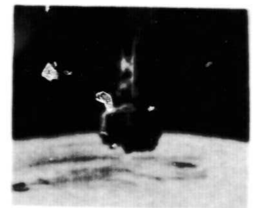
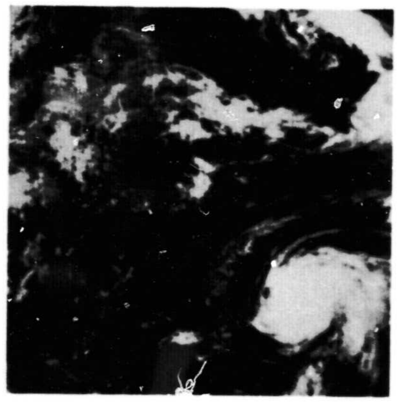
NIMBUS III

TRACKS
HURRICANE CAMILLE



Photographic coverage of Camille, one of the deadliest hurricanes in recent history, begins with a picture of the storm's infancy on 11 August 1969. Camille was christened a tropical storm on 14 August and reached hurricane strength the following day. It then swept through the southeastern U.S. and back into the Atlantic where it is shown in the last photo with hurricane Debbie.



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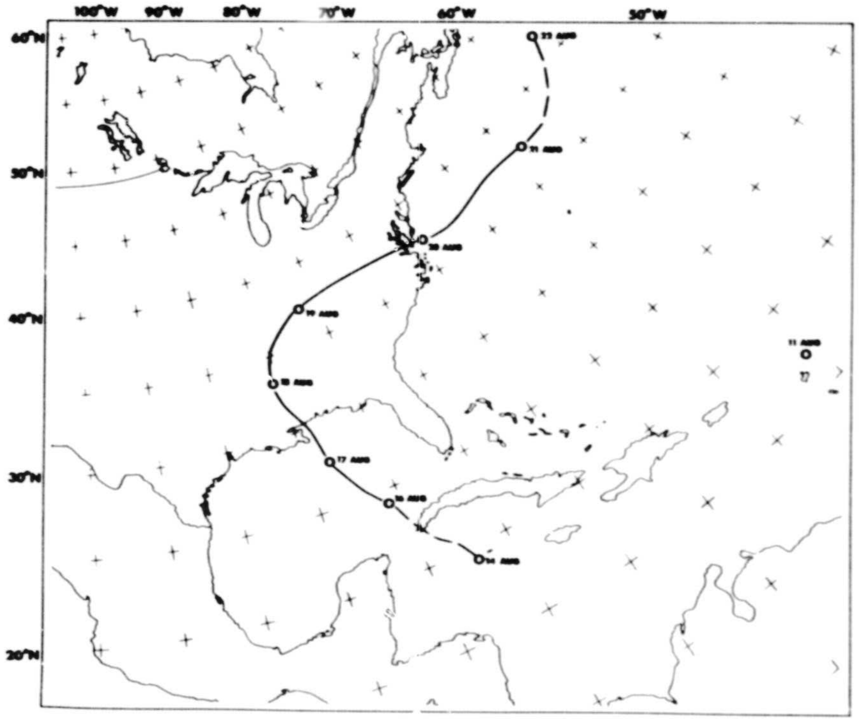

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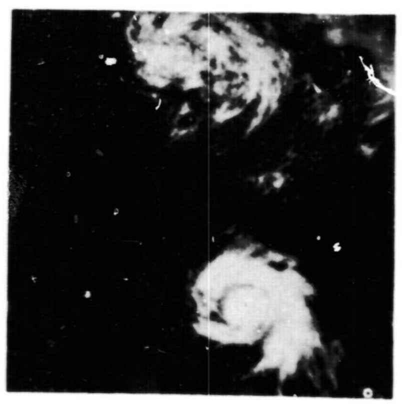

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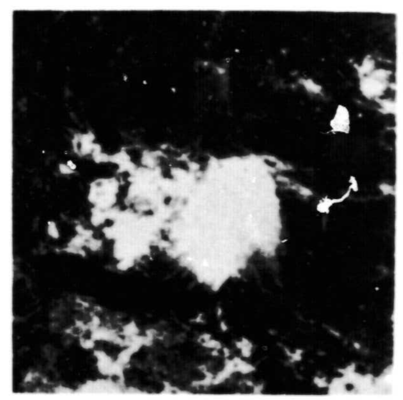

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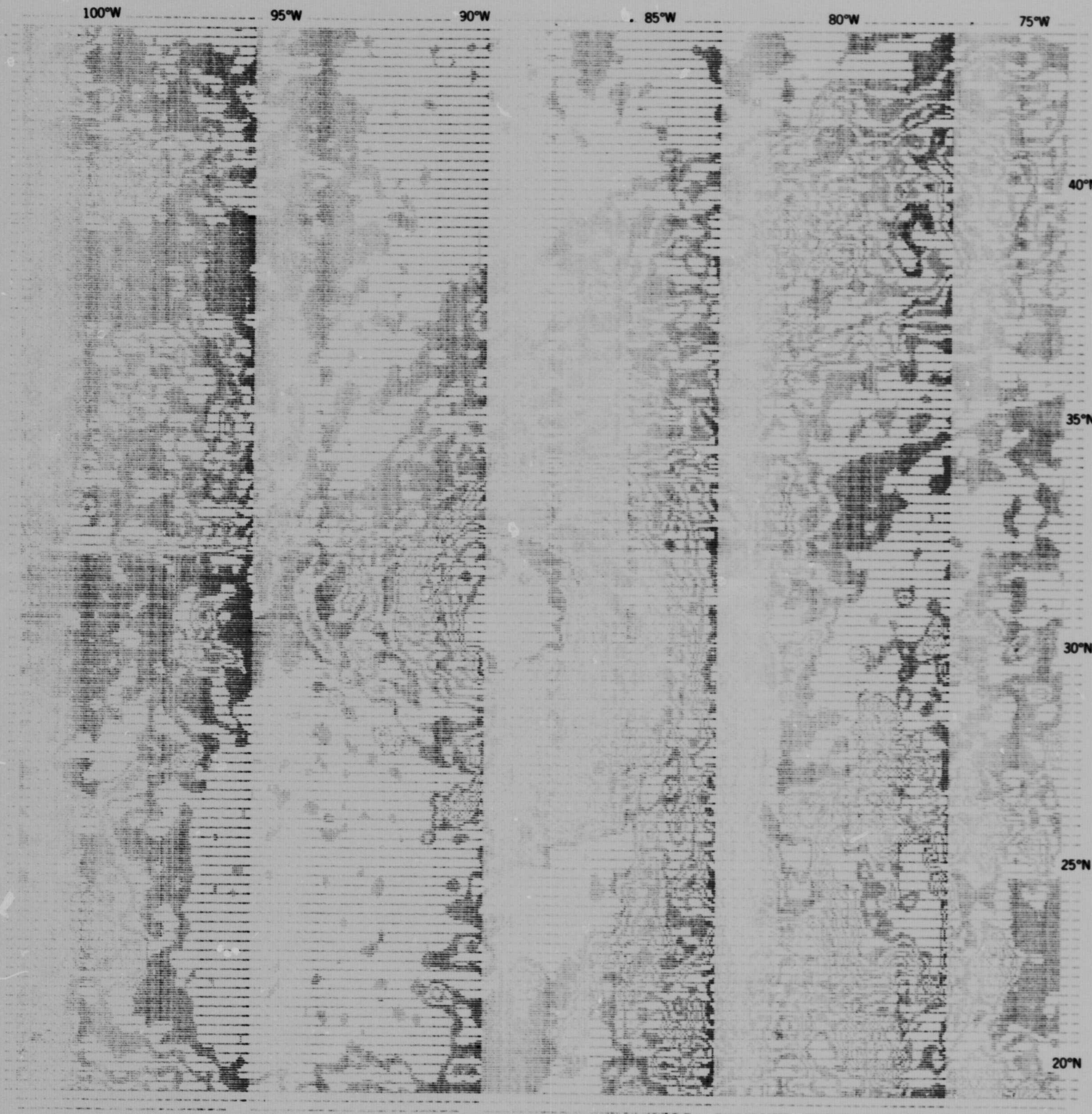
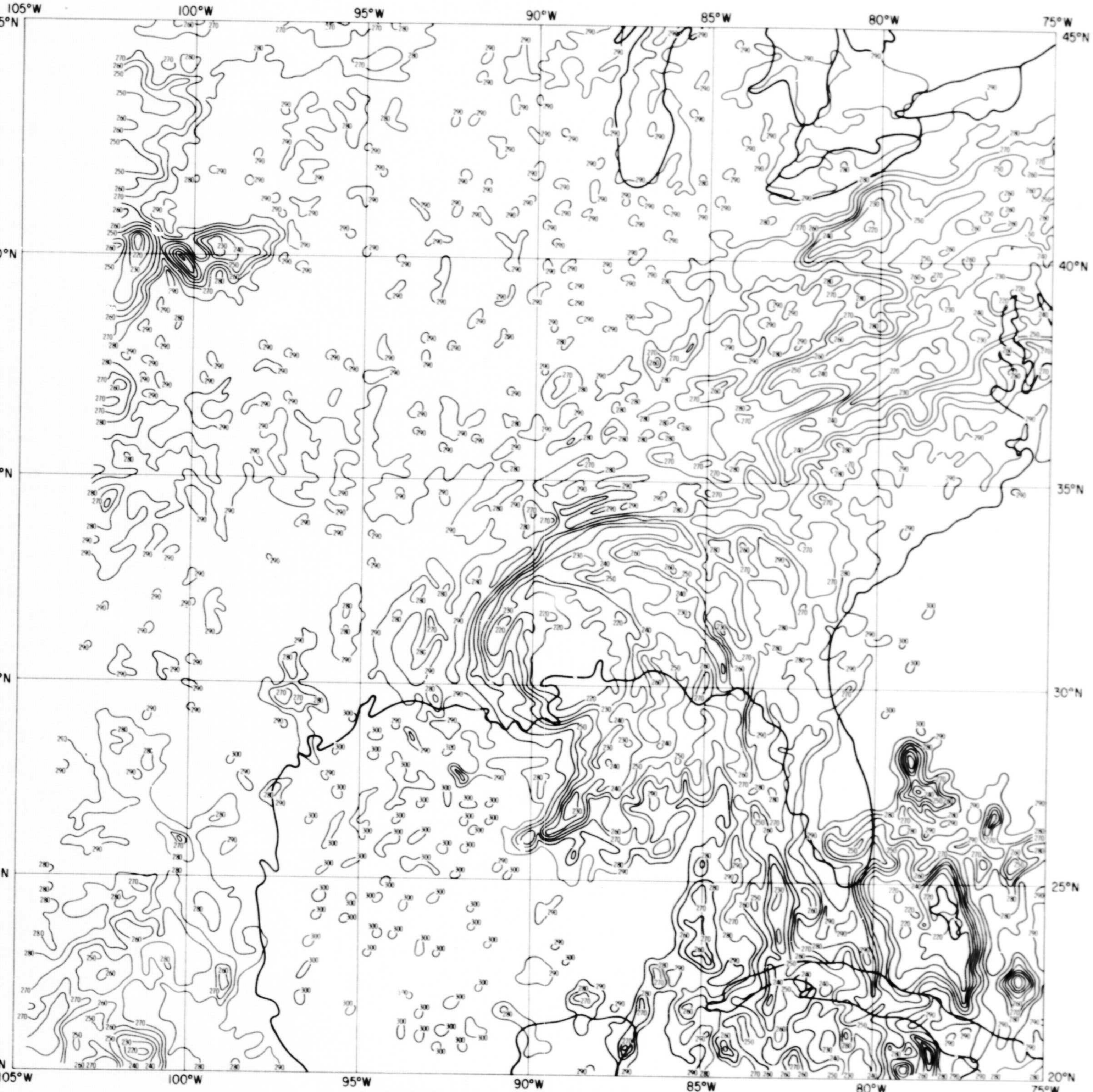


HURRICANE CAMILLE

NIMBUS III HRIR AUGUST 18, 1969

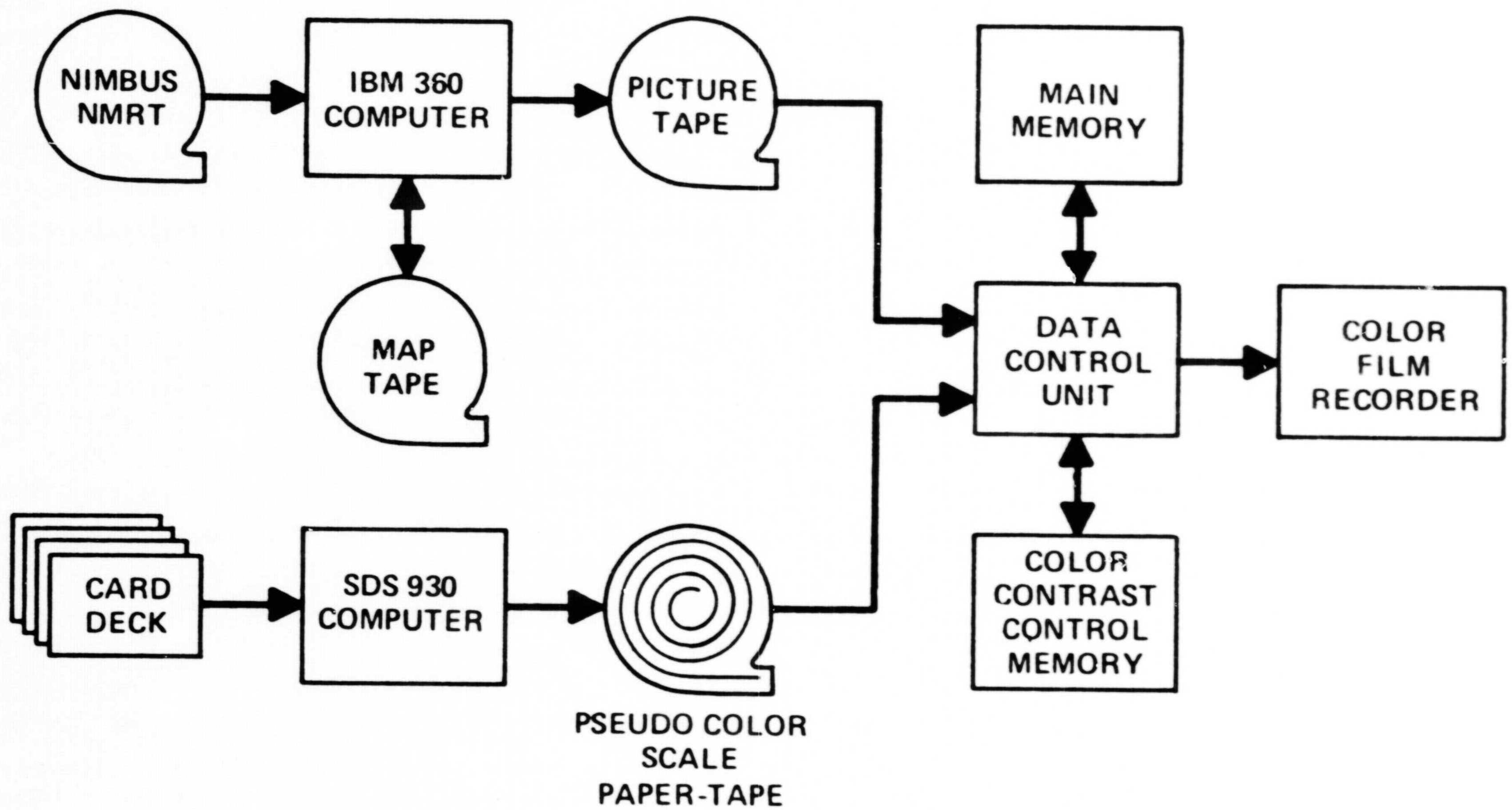
EQUIVALENT BLACKBODY TEMPERATURE (°K)



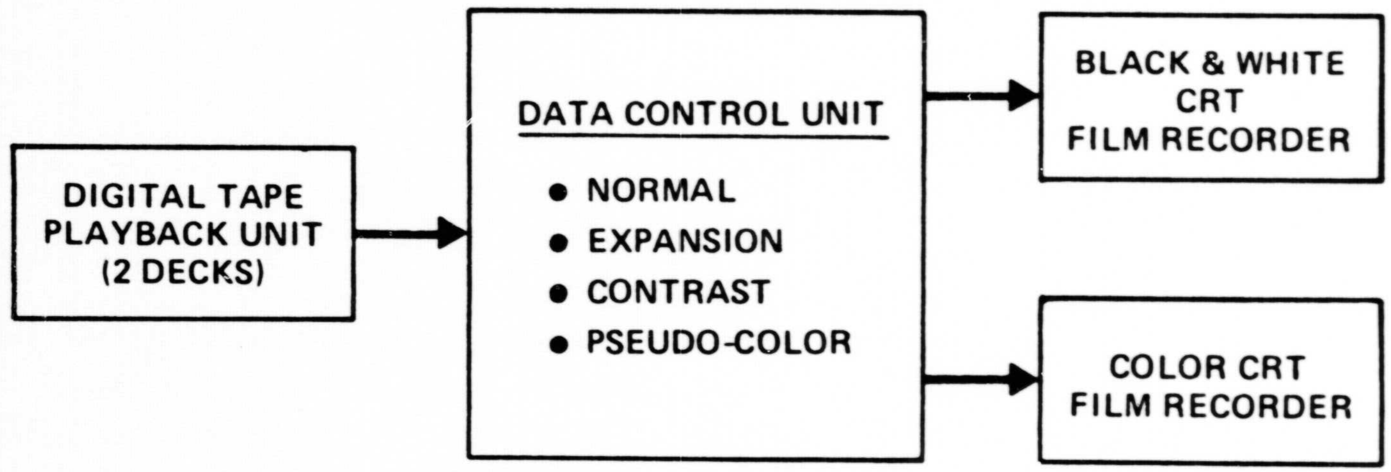
HURRICANE CAMILLE

NIMBUS III HRIR AUGUST 18, 1969

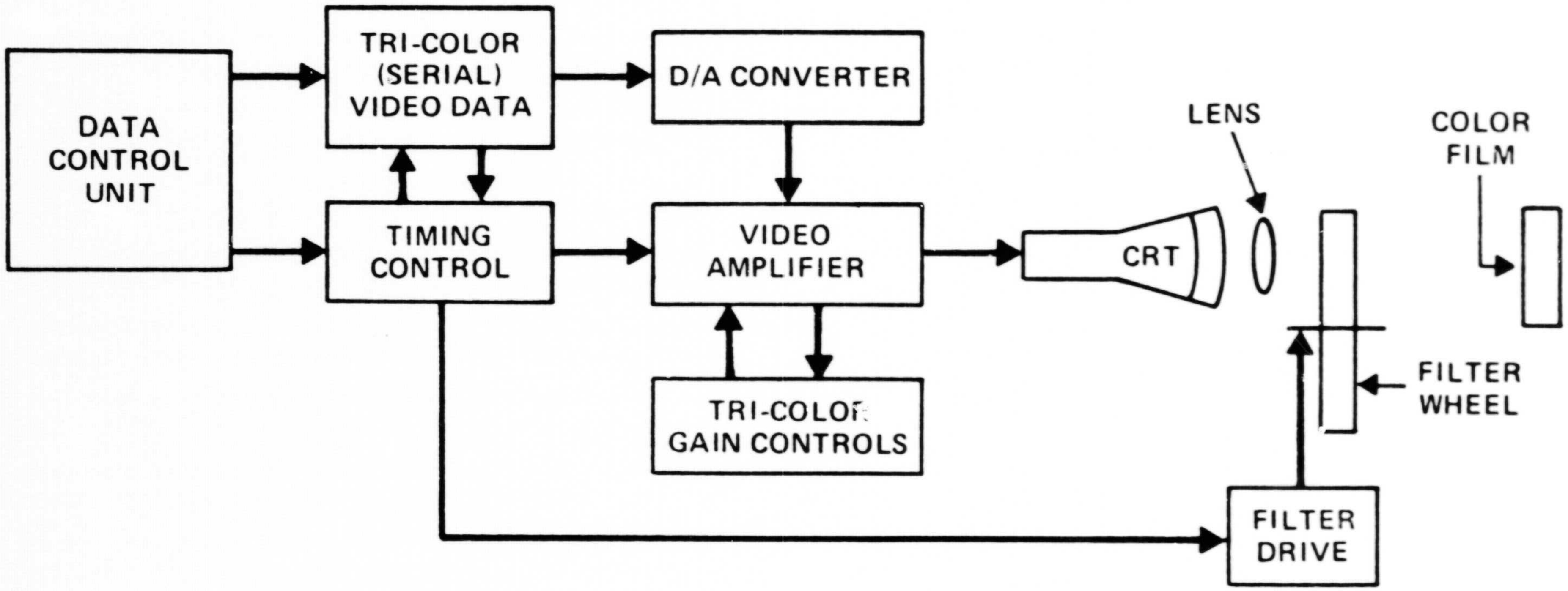
EQUIVALENT BLACKBODY TEMPERATURE (°K)



PSEUDO COLOR PROCESSING OF NIMBUS HRIR DATA



APPLICATIONS TECHNOLOGY SATELLITE OPERATIONS
CONTROL CENTER (ATSOCC)



EIS COLOR FILM RECORDER